Highly Accelerated Life Testing

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The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Government sponsorship acknowledged.

Overview

- HALT/HASS Overview
  - Highly Accelerated Life Testing
  - Highly Accelerated Stress Screening
- Challenges with HALT
- Simulating a coring environment on Mars
- HALT as part of an environment test program

Caveats

- I have not performed a true HALT/HASS program.
  - Utilized HALT chamber to simulate a coring environment on Mars.
- In preparation for this test, attended a HALT training seminar at Hobbs Engineering in Denver, Colorado.
- Unless otherwise stated, most of the presentation materials are my interpretation & understanding of HALT.

HALT/HASS Overview

HALT/HASS

HALT: Highly Accelerated Life Testing

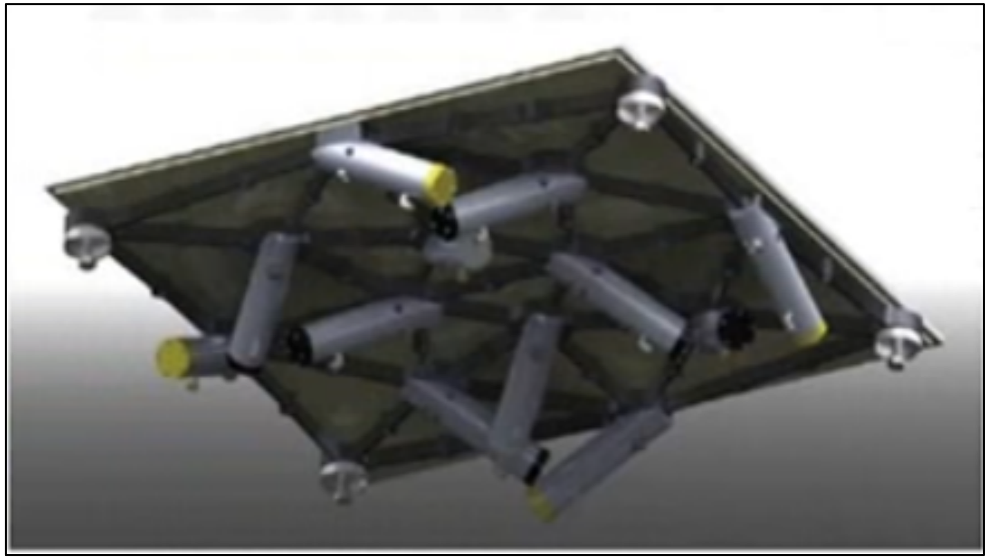
- HALT is the concept of iteratively developing a component through identifying failure modes as quickly as possible, implementing a design change/corrective action, and repeating the process until a robust design is developed.
- HALT is implemented by exposing the prototype to increasing magnitudes of
    - Temperature
    - Vibration/Repetitive-Shock
    - Voltage (not covered in this presentation)

  Until the prototype fails.
- Failure includes both Operational Limit (intermittent functional failure) and Destruction Limit (permanent failure).
- ***HALT is not an environmental test!***

HASS: Highly Accelerated Stress Screening

- After component maturity, HASS is used to screen components for latent failures after assembly.
    - Analogous to minimum workmanship.
- HASS is performed within the Operation Limits identified during HALT.

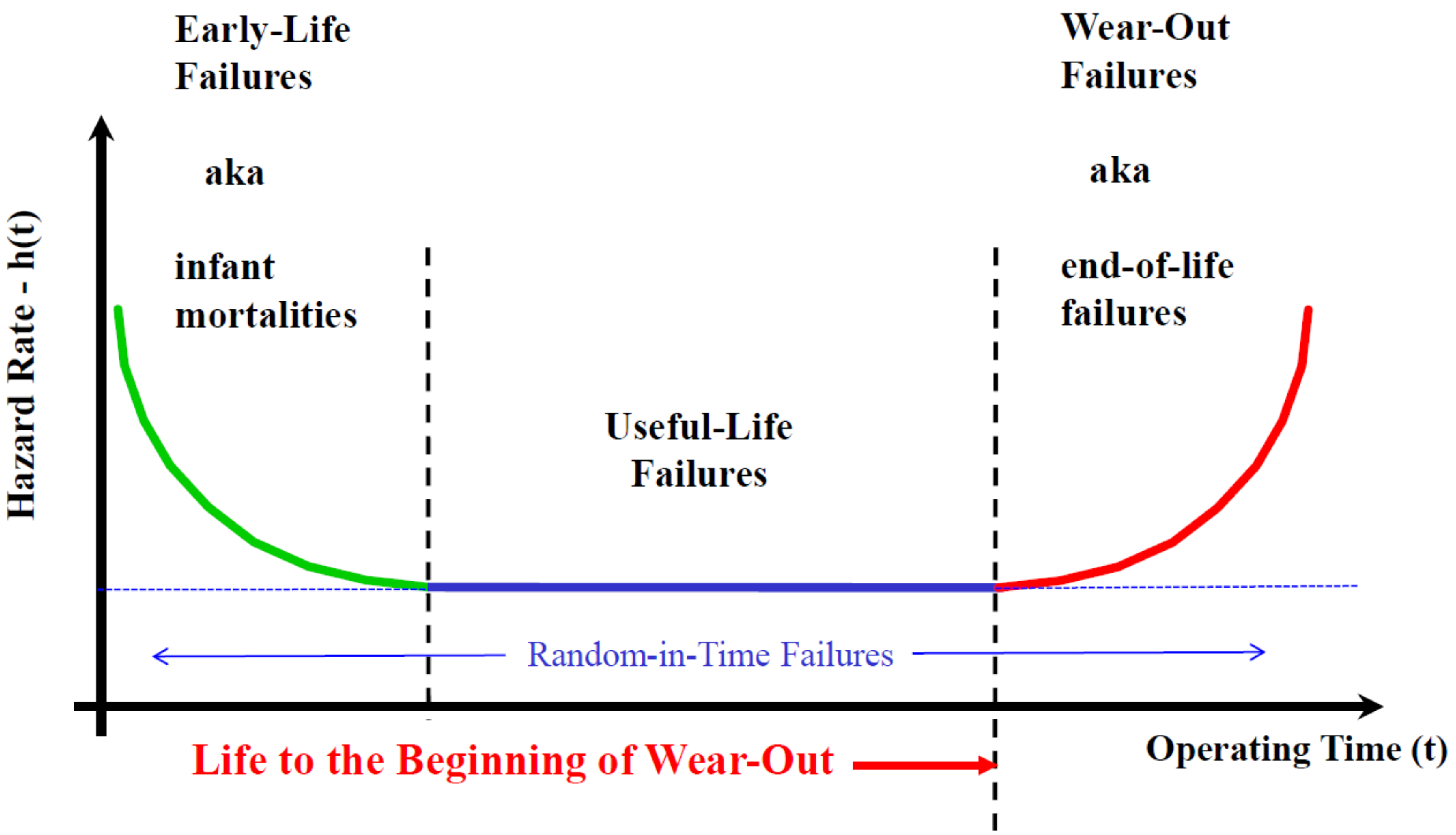
HALT Chamber



Underside of repetitive shock table with pneumatic actuator arrangement.

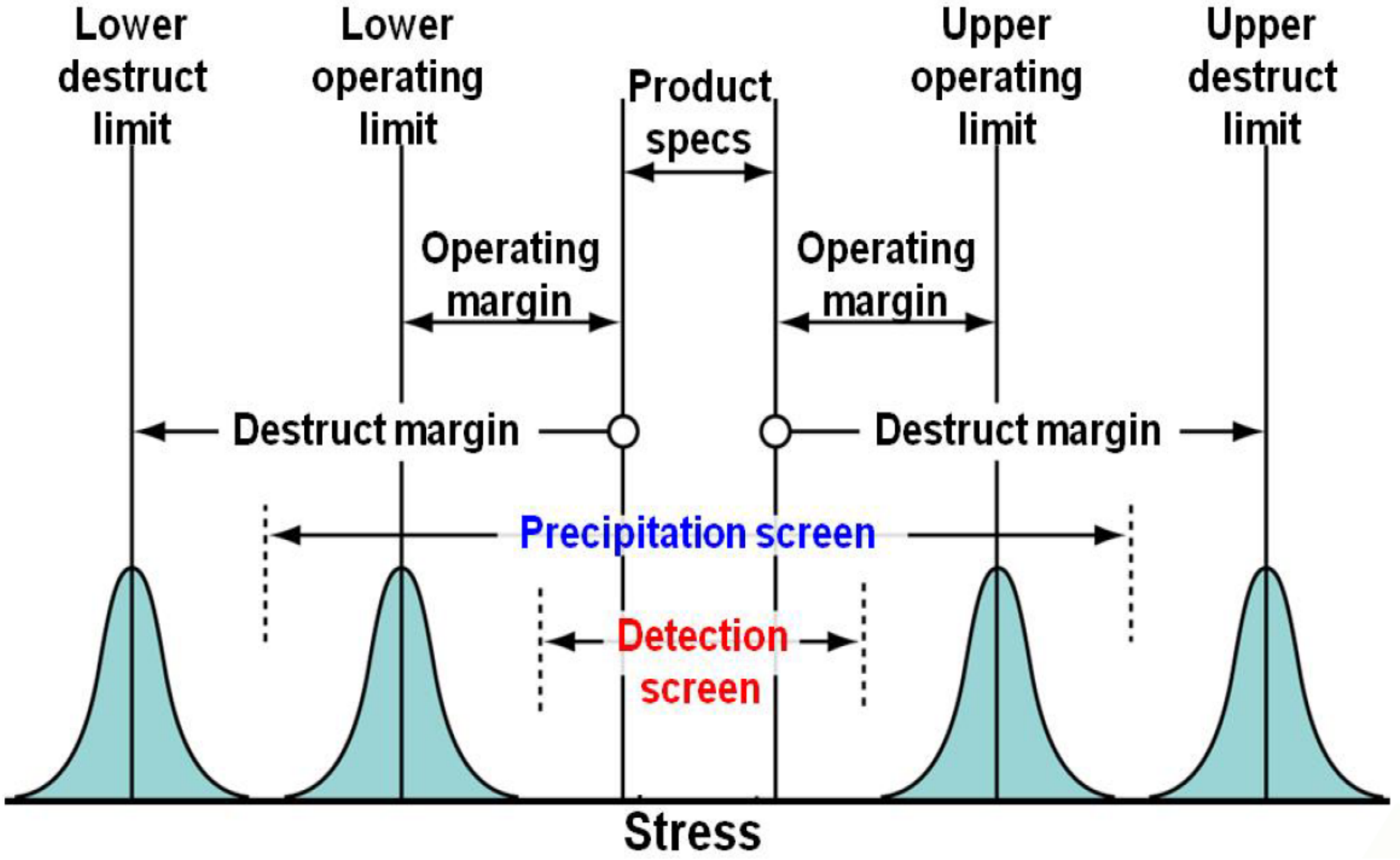
- Key differences from shaker table:
  - Semi-rigid table vs “infinite” impedance.
  - Single control accel for overall Grms control.
- Does offer live monitoring capability for hardware condition monitoring.

HALT: Robustness



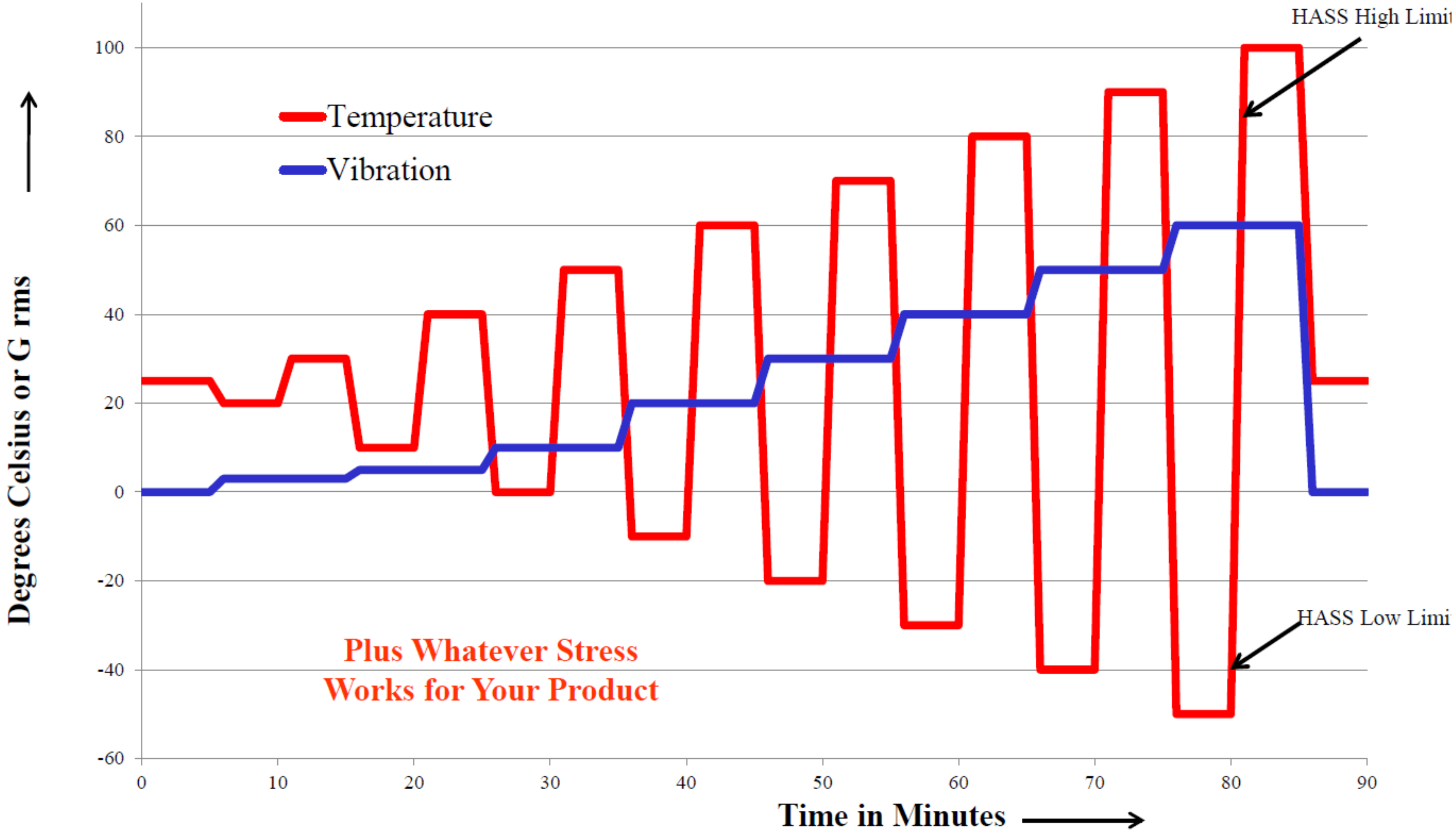
Provided courtesy of Aldo Fucinari, Rapid Discovery Systems

HALT/HASS Limits



Provided courtesy of Aldo Fucinari, Rapid Discovery Systems

Example of HALT Vibration/Temperature Profile



Provided courtesy of Aldo Fucinari, Rapid Discovery Systems

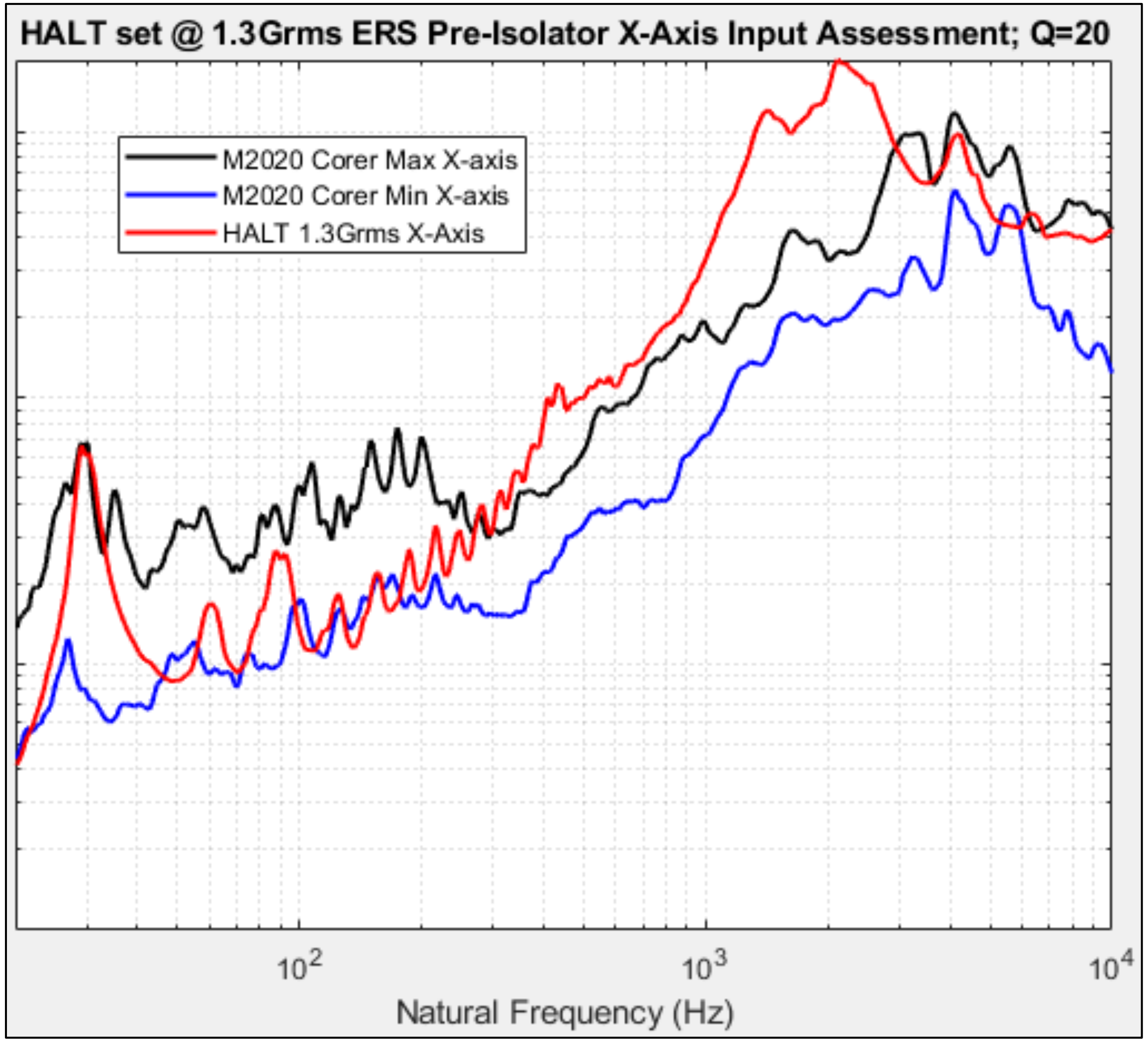
Challenges with HALT

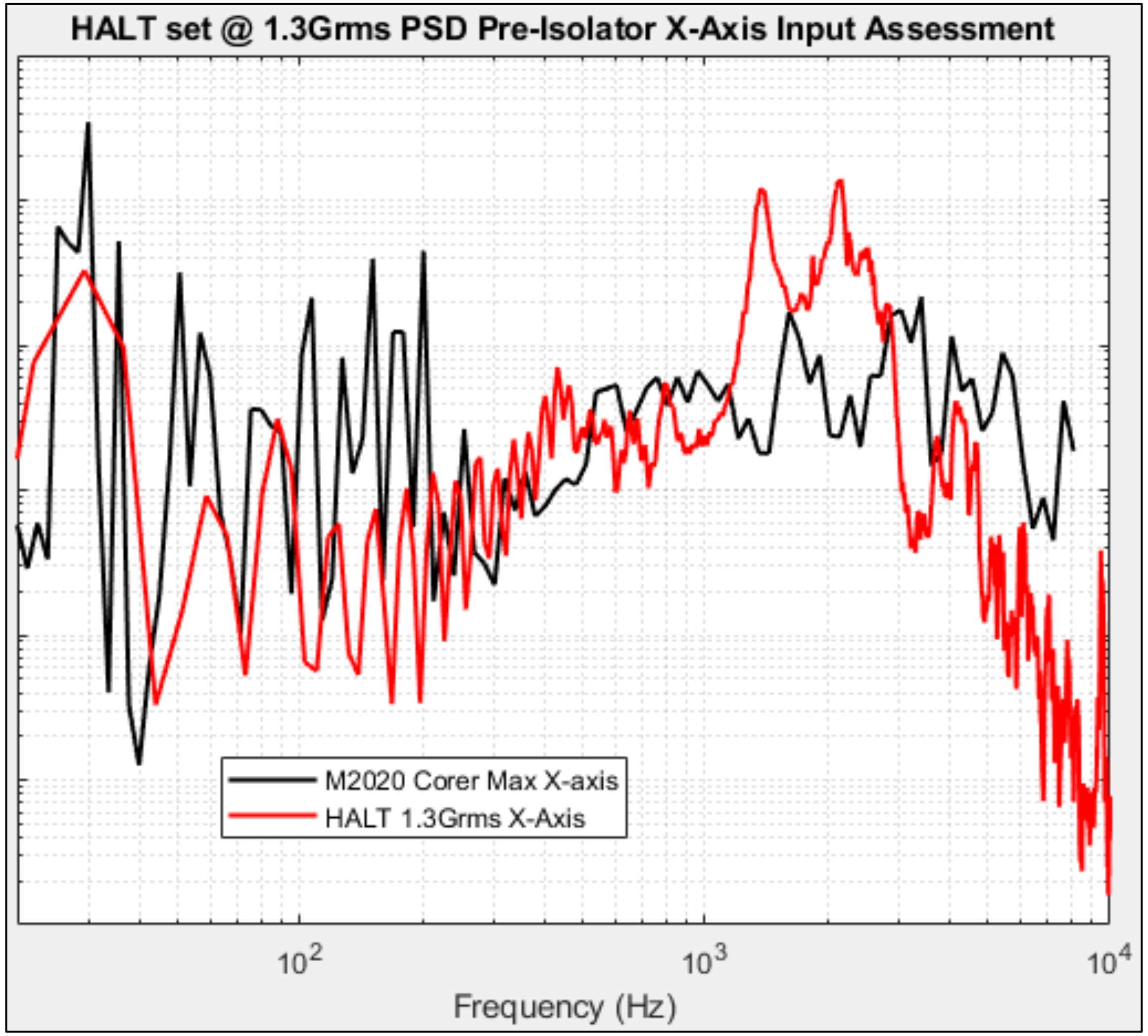
- Thought must be put into the fixture design to ensure that prototype is properly excited across the frequency spectrum.
  - The fixture itself can influence the environment seen on the prototype.
- Must iteratively fail prototypes. This could be cost prohibitive for single-build components/assemblies.
- Limited control of repetitive shock environment.
- Fault/Failure detection is critical to making improvements to prototypes.
  - Must be able to identify:
    - Hard failures
    - Soft failures
    - Intermittent failures

Simulating a Coring Environment

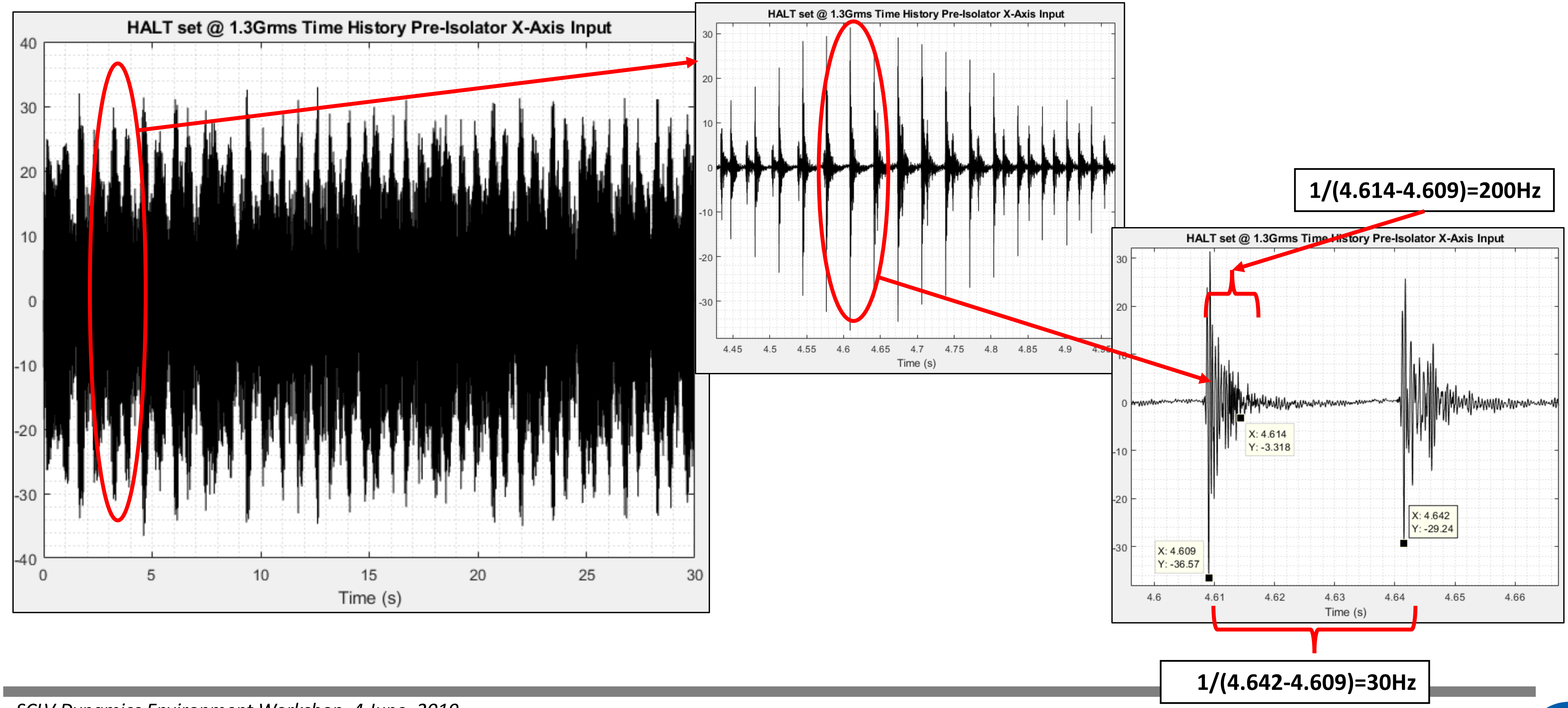
An atypical use of HALT Chamber Capabilities

Simulating a Coring Environment

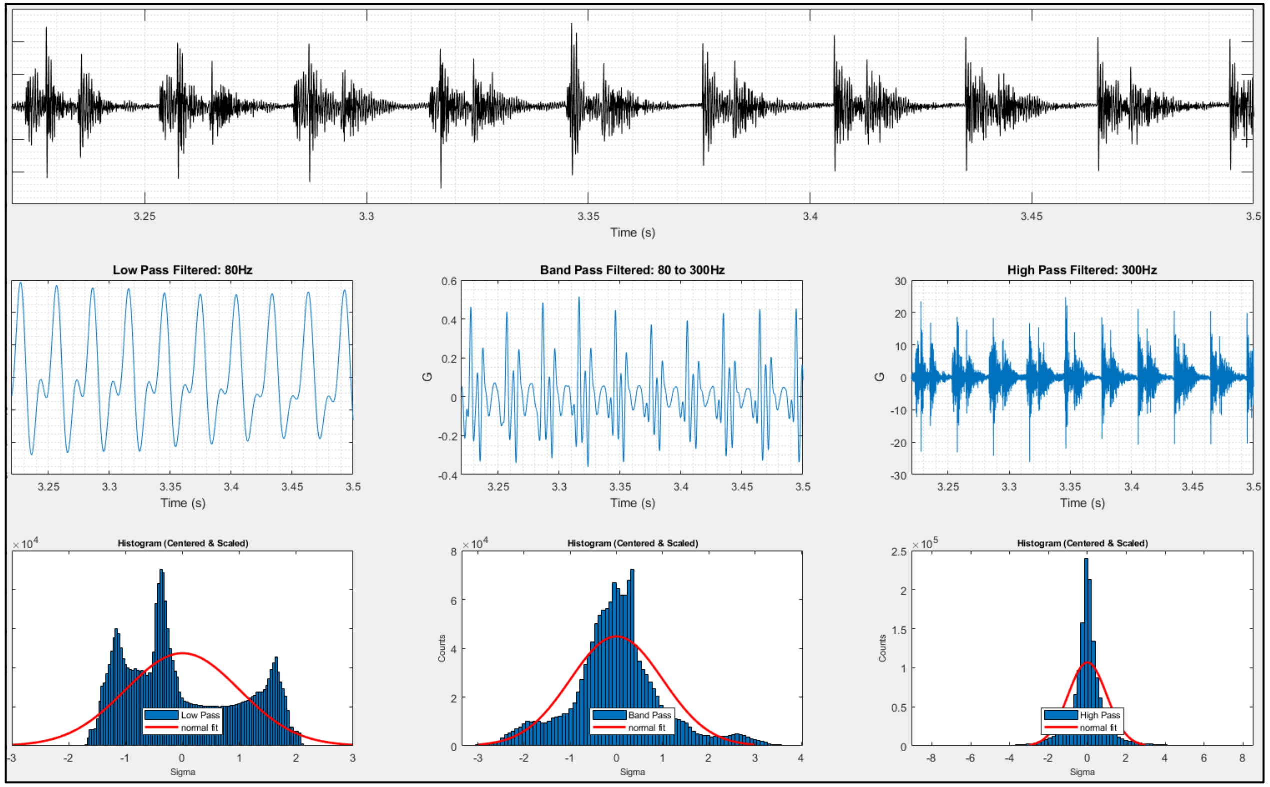




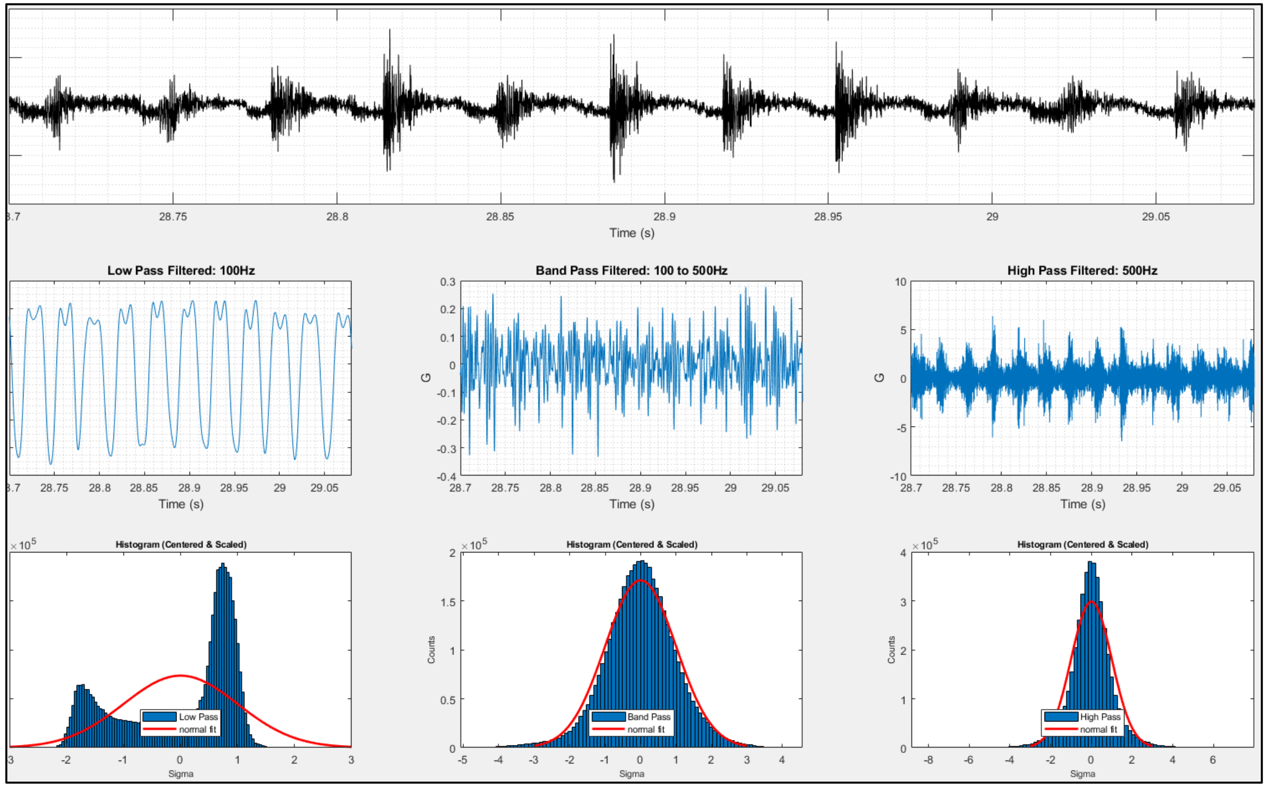
Simulating a Coring Environment Cont'd…



Coring Simulation Cont'd… Temporal Assessment



HALT



Corer

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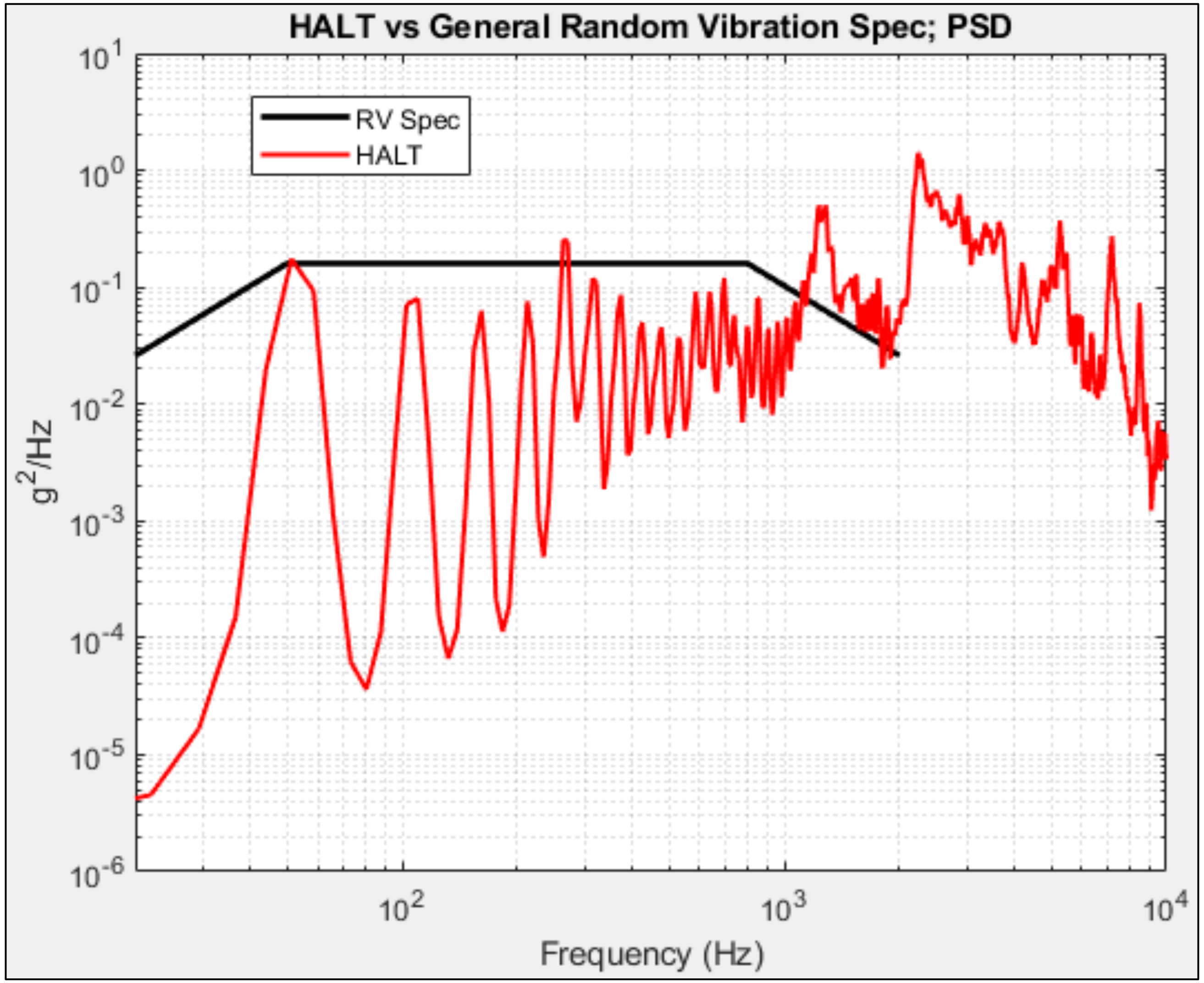
HALT & Environment Testing

Typical HALT PSD Compared to General Spec

- HALT does not need to be repeated ad infinitum:
  - Once component can withstand HALT levels at or above MPE, could stop process; however, this limits value of HASS.
- Majority of power is above 1kHz & is multi-axis excitation.
- HALT & HASS lends itself better to components that can be prototyped and multiple will be used. E.g. cable connectors, actuator motors, etc.



Summary

- HALT/HASS testing is a testing/development philosophy which emphasizes hardware robustness over designing hardware to a specific environment requirement.
    - *HALT is not a replacement to an environmental test program.*

- While this method may have limited value for single-development hardware, there are likely niche application within spacecraft/launch vehicle development in which HALT/HASS would be beneficial and perhaps more efficient that traditional development methods.

- While JPL has primarily used HALT to simulate a Mars coring environment, moving forward JPL is considering applications in which HALT/HASS would offer advantages over the traditional approach.

QUESTIONS?

BACKUP

HOBBS ENGINEERING

A DIVISION OF QUALMARK

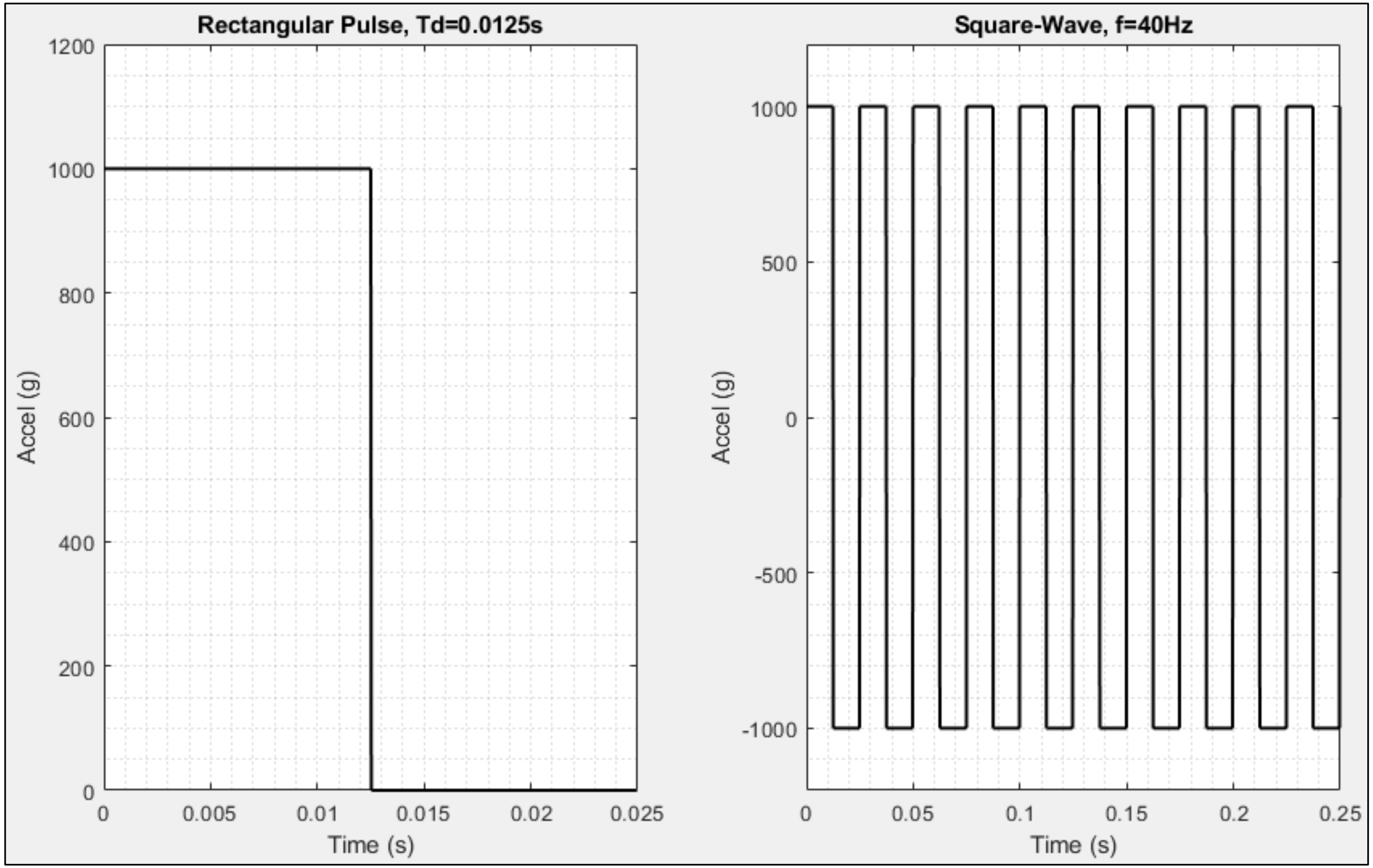
HALT & HASS SEMINAR PLUS WORKSHOP

Aldo Fucinari – Instructor

Rectangular Pulse & Square-Wave

- Ideal rectangular pulse of pulse width, T_d, and amplitude A.
- Undamped SDOF to ideal rectangular pulse modeled as,

- When the pulse is repeated (A_w=±A & $T_p=2T_d$) to form a square-wave, the periodic pulse can be approximate with Fourier series expansion to:
  - $Z(t) = \frac{4A_W}{\pi}\sum_{n=1,3,\ldots}\frac{1}{n}\sin(n\Omega t)$
- Where $\Omega=2\pi/T_p$.



Rectangular Pulse & Square-Wave SDOF Response

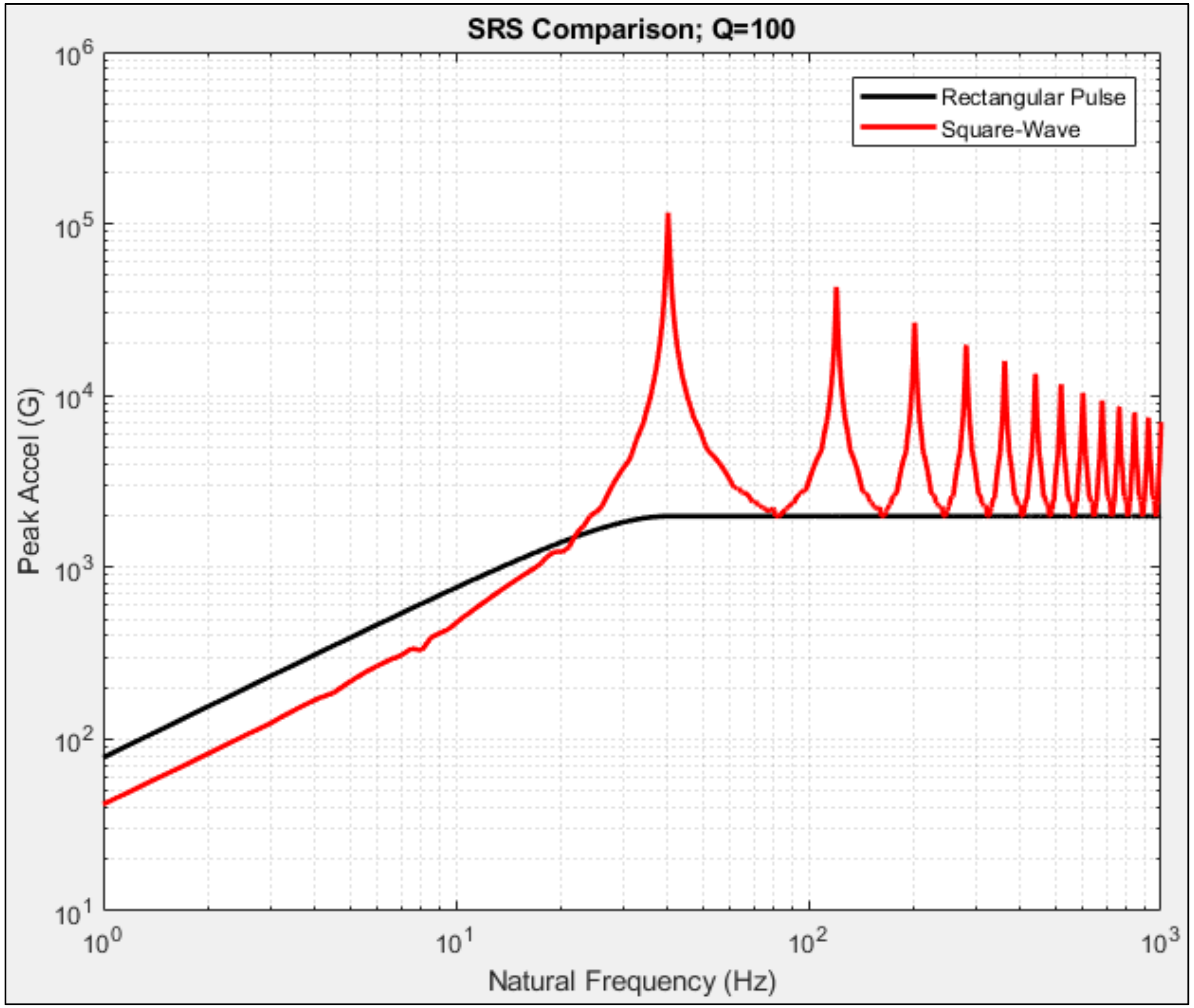
Dynamic Amplification Factor, R.

Undamped SDOF Response to Rectangular Pulse,

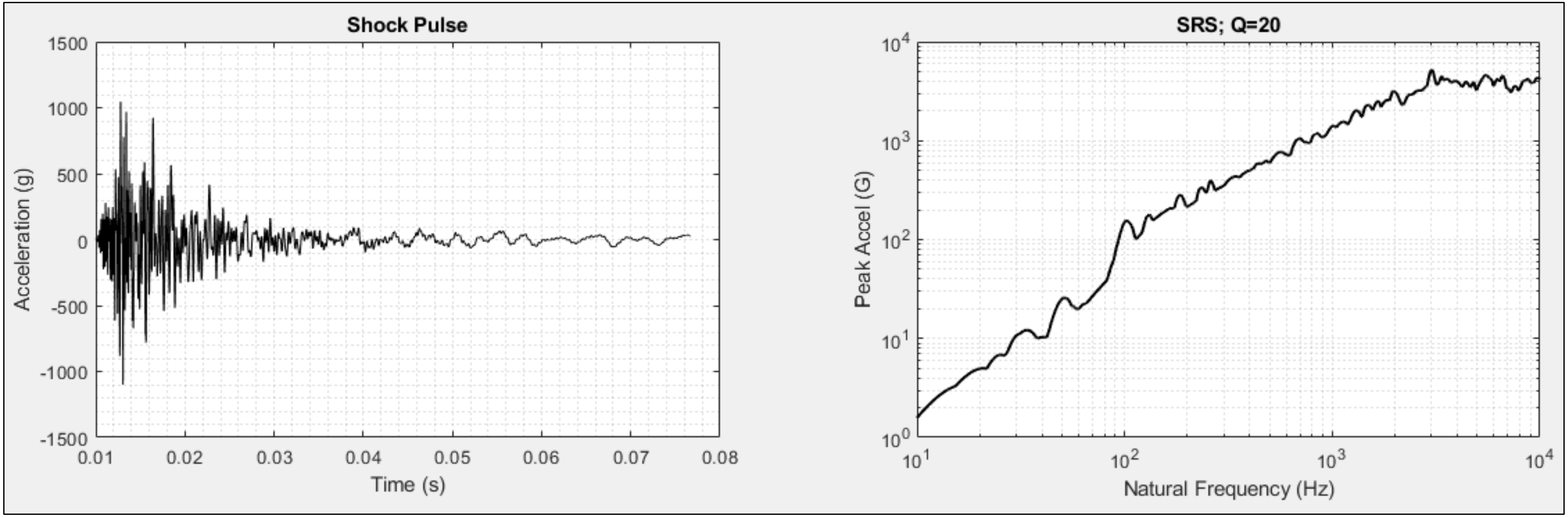
- For $T_d \geq 0.5T_n$ (Force-Vibration), where $T_n = 2\pi/w_n$,
  - $R_1 = 1 - \cos(w_n t)$ and $R_{1max} = 2$
- For $T_d < 0.5T_n$ (Residual-Response),
  - Free vibration with I.C. $R_1(T_p)$ & $\dot{R_1}(T_p)$.
  - & $R_{2\_max} = 2\sin(\frac{\pi T_d}{T_n})$.

Undamped SDOF Response to Square-Wave,

- $R = \sum_{n=1,3,\ldots} \frac{(\frac{n\Omega}{\omega_n})^2}{1-(\frac{n\Omega}{\omega_n})^2} * \frac{4}{n\pi} * \sin(n\Omega t)$
- Coupling can now occur when $w_n = n\Omega$.
- SRS indicates that, for $w_n \geq \Omega$, the peak response to the square-wave is equivalent to the max response to a rectangular pulse when $w_n = (n+1)\Omega$.



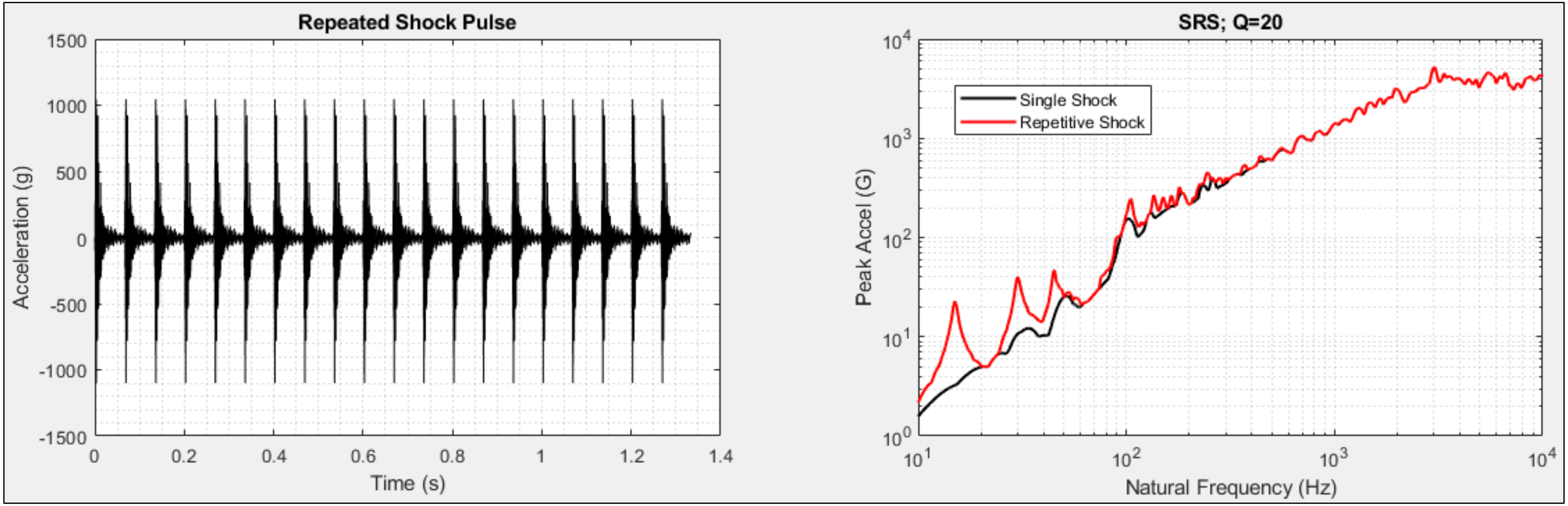
Repetitive Shock Description



Single Shock Pulse Statistics
Amplitude Stats
mean = 0.0
std dev = 129.4
RMS = 129.4
skewness = 0.116
kurtosis = 18.02

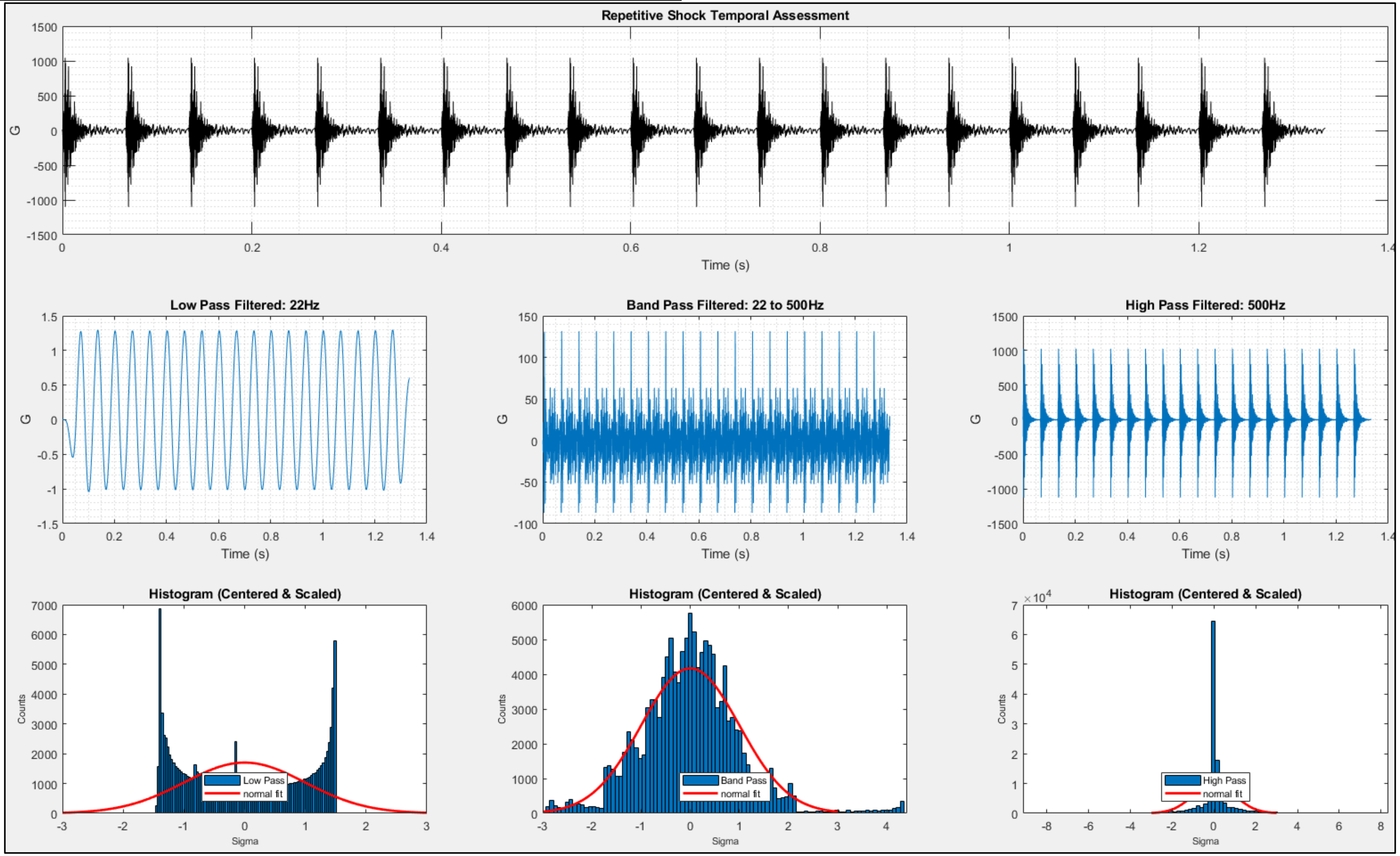
Maximum = 1045
Minimum = -1100
Crest Factor = 8.497

Repetitive Shock Description Cont'd…



Similar observations as the rectangular pulse and square-wave example.

Temporal Characteristics



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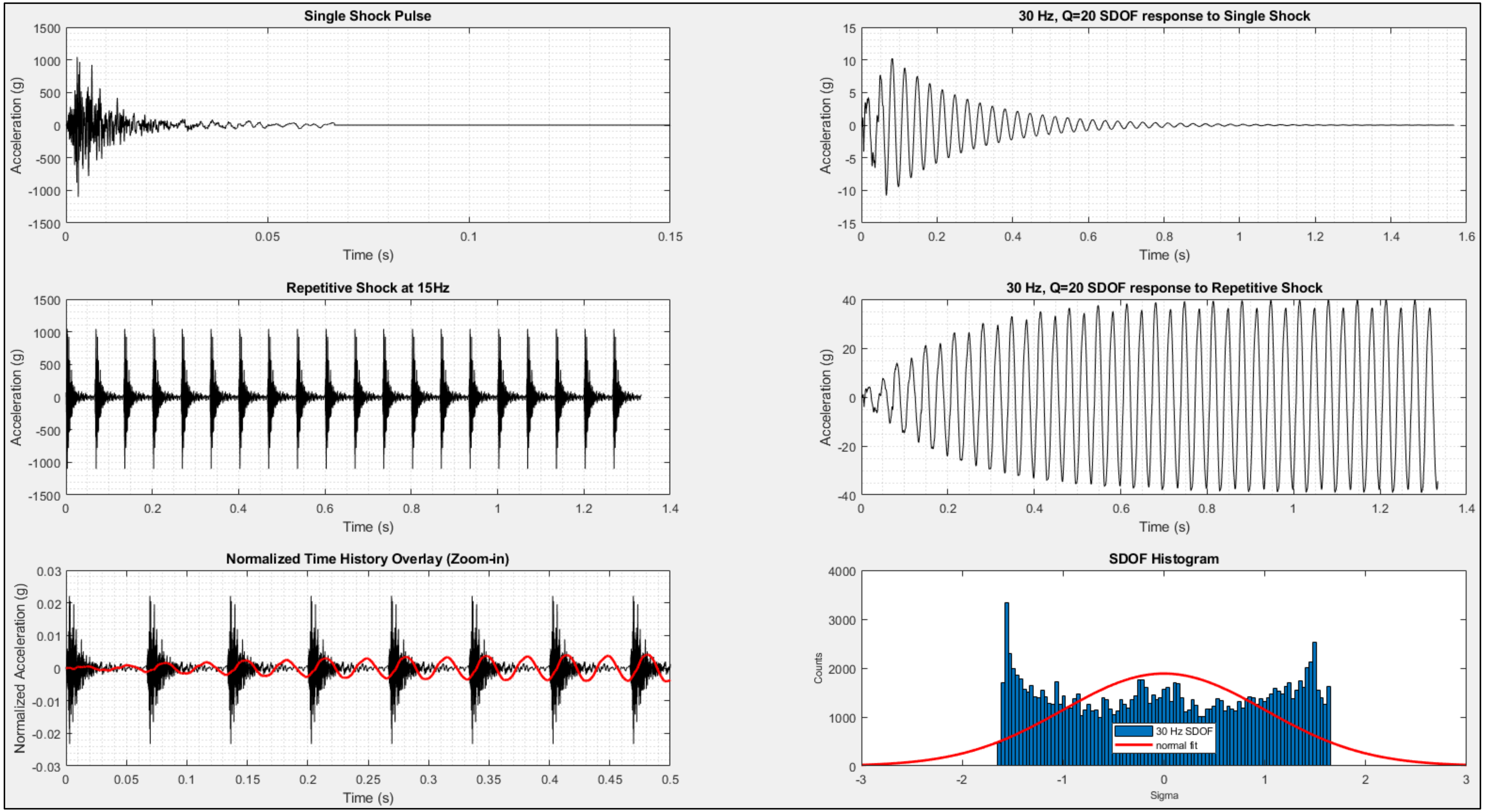
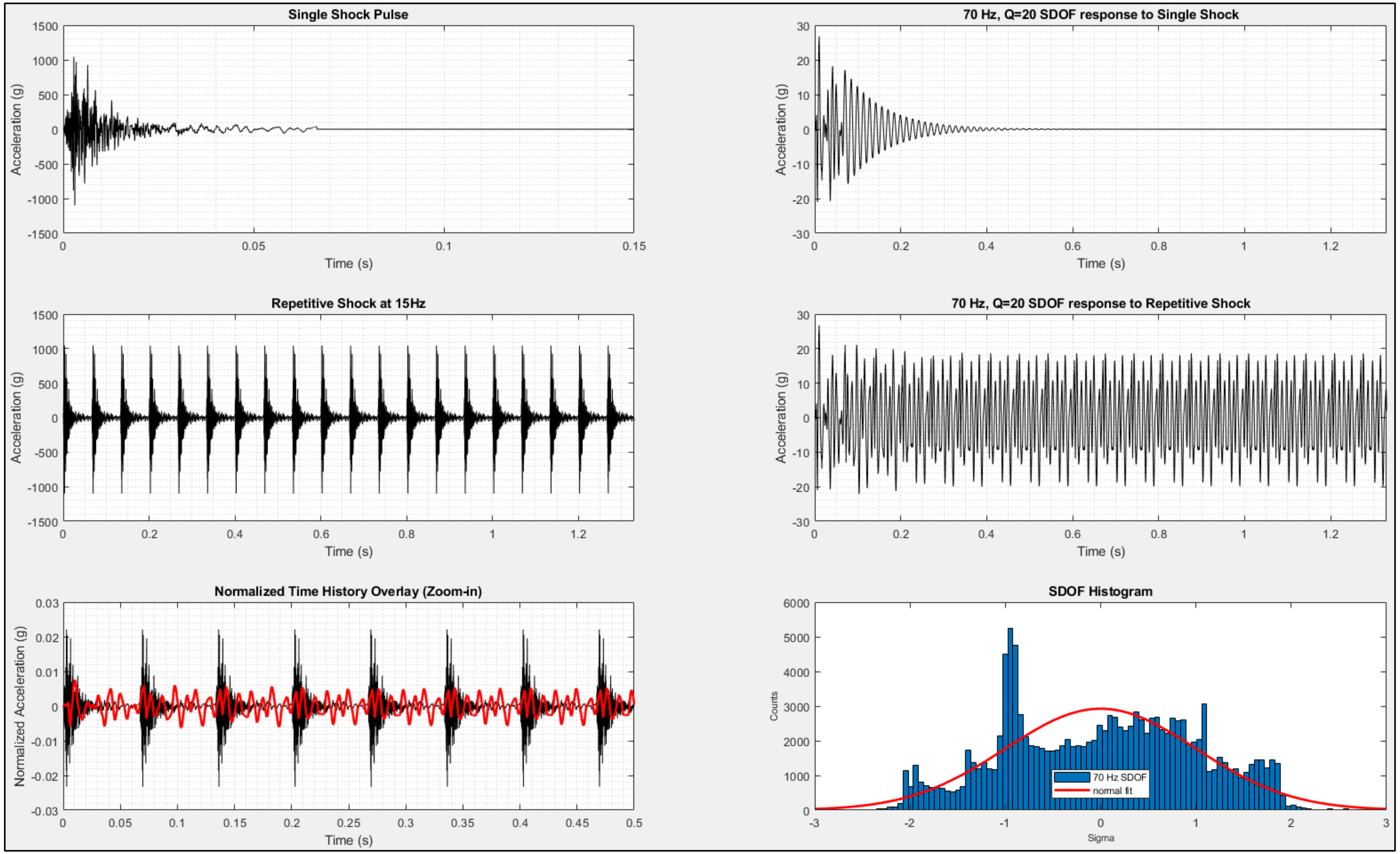
SDOF Response



SDOF Response Cont'd…



SDOF Response Cont'd…